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A ROUGH ESTIMATE OF THE "BLACKOUT" TIME IN RE-ENTRY COMMUNICATIONS

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I. Introduction:

A review of the computation methods of re-entry communications taking into account all important thermodynamic, physico-chemical, and transport phenomena in the shock layer and those related to the wave propagation shows that so many parameters are involved in the computations that accurate and rigorous calculations are almost impossible. Inaccuracies of the data necessary for the computations also reduce the value of accurate calculations. By using averaged available data and introducing approximations evenly distributed in all phases of the computations, however, useful estimates of the re-entry communications problem seem possible.

In this report an approximate method for estimates of the "blackout" times and durations at re-entry are derived which is applicable under specific operational conditions usually fulfilled in manned space flight.

In manned space flight, the vehicles are relatively large. As a consequence, equilibrium conditions can be used for the approximate flow-field computations. This is permitted since the relaxation times of the reactions are small compared with the travel times of the particles within the stream tubes between regions of large differences of medium properties. Another condition to be fulfilled is that the thickness of the shock layer Δ along the transmission path and the dimensions of the antennas are not small compared with the wavelengths.

Under these conditions we can express the attenuation for the under-dense (u) and over-dense (o) plasma sheaths by the following approximations[1/]:

$$R_{tot}^{(u)} \approx 0.012 \; N_S \, \nu_S \, F_1 \, G_1 \, \delta_{eq} / f^2 , \qquad (1)$$

$$R_{tot}^{(o)} \approx 0.23 \times 10^{-4} \sqrt{F_1} \sqrt{N_S} \, \delta_{eq} . \qquad (2)$$

The various quantities in these equations are:

N_s, ν_s — Electron density and collision frequency behind a normal shock.

F_1, G_1 — Geometry factors for the electron density and collision frequency.

1/ F. J. Tischer: Attenuation in Re-Entry Communications. Plans Office Technical Report No. 2 (X-520-62-92), Goddard Space Flight Center.

δ_{eq} Equivalent plasma layer thickness.

f Operational frequency.

A typical diagram for the attenuation is shown in Figure 1, where the regions of the validity of Eqs. (1) and (2) are indicated by the corresponding numbers. Between these two regions, rigorous computation is necessary.

The diagram shows that, when a space vehicle re-enters the atmosphere, the attenuation suddenly increases to large figures when f_p/f becomes larger then one. This condition starts when the electron density in a near-body streamline in front of the antenna begins to exceed the critical electron density for the operational frequency. For the corresponding boundary value f_{po}, we can write

$$f_{po} = f = 9000\sqrt{N_S F_1} \quad . \tag{3}$$

We can now explore the above relations for estimates of the "blackout" times in re-entry communications.

II. Description of the Method:

Combination of the relations of the preceding sections with the trajectory data for a specific flight permits computation of the times when communications enters and leaves "blackout" as a function of frequency.

The trajectory data are usually given by presentations of the altitude and velocity as a function of total flight time, re-entry time, or position. The values of altitude and velocity permit then the determination of the maximum electron density N_s and plasma frequency f_{ps} in the stagnation region behind the normal shock for each point of the trajectory using tables or diagrams found in the literature. Figure 2 shows a plot published by Sisco and Fiskin.[2/] Evaluation of the Mercury MA-6 trajectory yields values of the plasma frequency as a function of total flight time plotted in Figure 3. Under the time scale, the altitude of the vehicle is indicated.

The next step is the determination of the geometry factor for the electron density F_1 which interrelates the maximum value N_e within the shock layer in front of the antenna with the electron density behind the shock front in front of the vehicle according to

$$N_e = N_s F_1 \quad . \tag{4}$$

Rough estimates from flow-field considerations and evaluation of the records of the fieldstrengths measurements during the MA-6 flight furnished by the Manned Space Flight Support Division, Goddard Space Flight Center give for the geometry factors

2/ W. B. Sisco and J. M. Fiskin: Basic Hypersonic Plasma Data of Equilibrium Air for Electromagnetic and Other Requirements. In "Electromagnetic Effects of Re-Entry". Pergamon Press, New York, New York, 1961.

$$F_1 \approx 10^{-2.5} \text{ (C-Band Antennas)},$$

and

$$F_1 \approx 10^{-2.7} \text{ (TM-Antennas)},$$

for the Mercury capsule. As an approximation, the geometry factor F_1 is constant in the region between 25 to 100 KM. Using the above values, we obtain for the maximum plasma frequencies $f_p^{(-2.5)}$ and $f_p^{(-2.7)}$ in front of the two antenna locations the values plotted in Figure 3.

The diagram shows that the plasma frequencies at the various locations increase continuously when the vehicle re-enters the dense atmosphere while the altitude decreases. They reach maxima at a time of approximately 287 minutes at an altitude of 55 Km. Due to the fast decrease of the velocity at and after this time, the plasma frequency also begins to decrease very rapidly.

The times for entering into and leaving "blackout" as a function of frequency can now be determined by finding the times when the curve for the considered antenna location reaches the value f_p equal to the operational frequency. Point P_1 on curve C indicates the "blackout" time for the telemetry frequency 260 MC. The point P_2 indicates the end of "blackout".

A plot of the "blackout" duration for the two antenna locations is shown in Figure 4 as a function of frequency.

It should be noted that a distinct cutoff of communications can be expected in the upper part of the curves in Figure 4. In the regions of increased slope, in the lower right-hand corner, the attenuation may reach high levels without interrupting communications.

A note of caution should be added. In using the above relations, it should be realized that the derivation includes many simplifications and approximations which limit the validity of this approach to specific structures as indicated in the introduction. Evaluation of additional experimental and real-flight data will permit determination of the errors and limitations and will permit the eventual introduction of correction factors.

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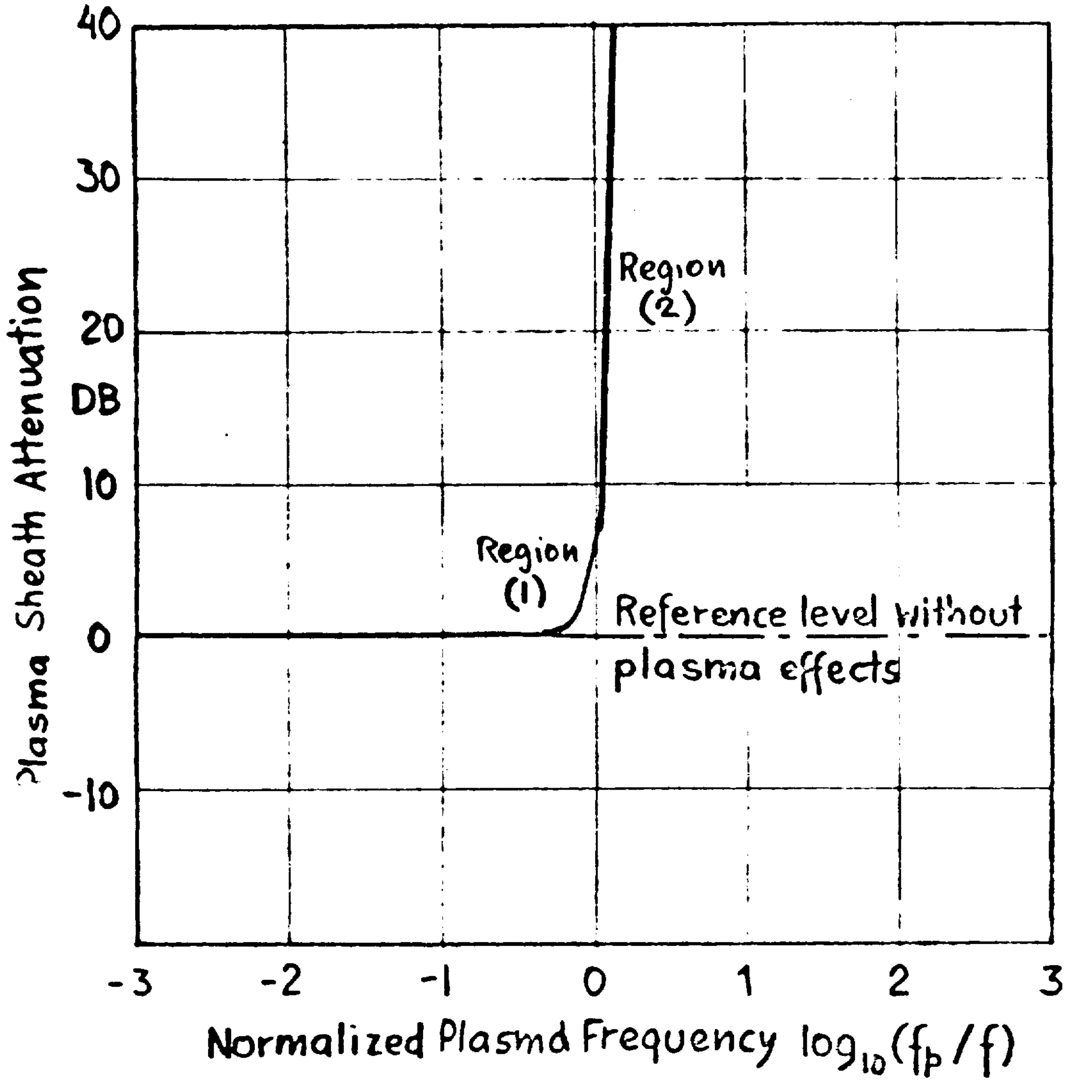

Fig. 1 Plasma Sheath Attenuation Versus Plasma Frequency

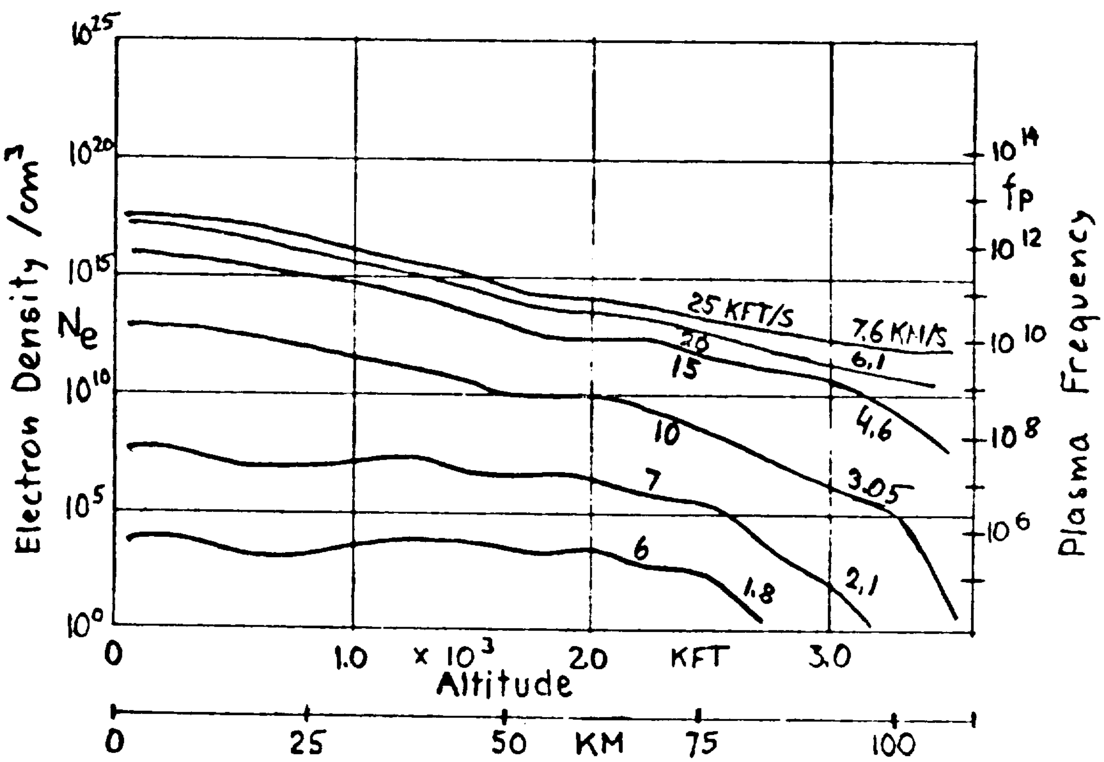

Fig. 2

Electron density and plasma frequency behind a normal shock versus altitude and velocity of the re-entry body (Sisko and Fiskin (27))

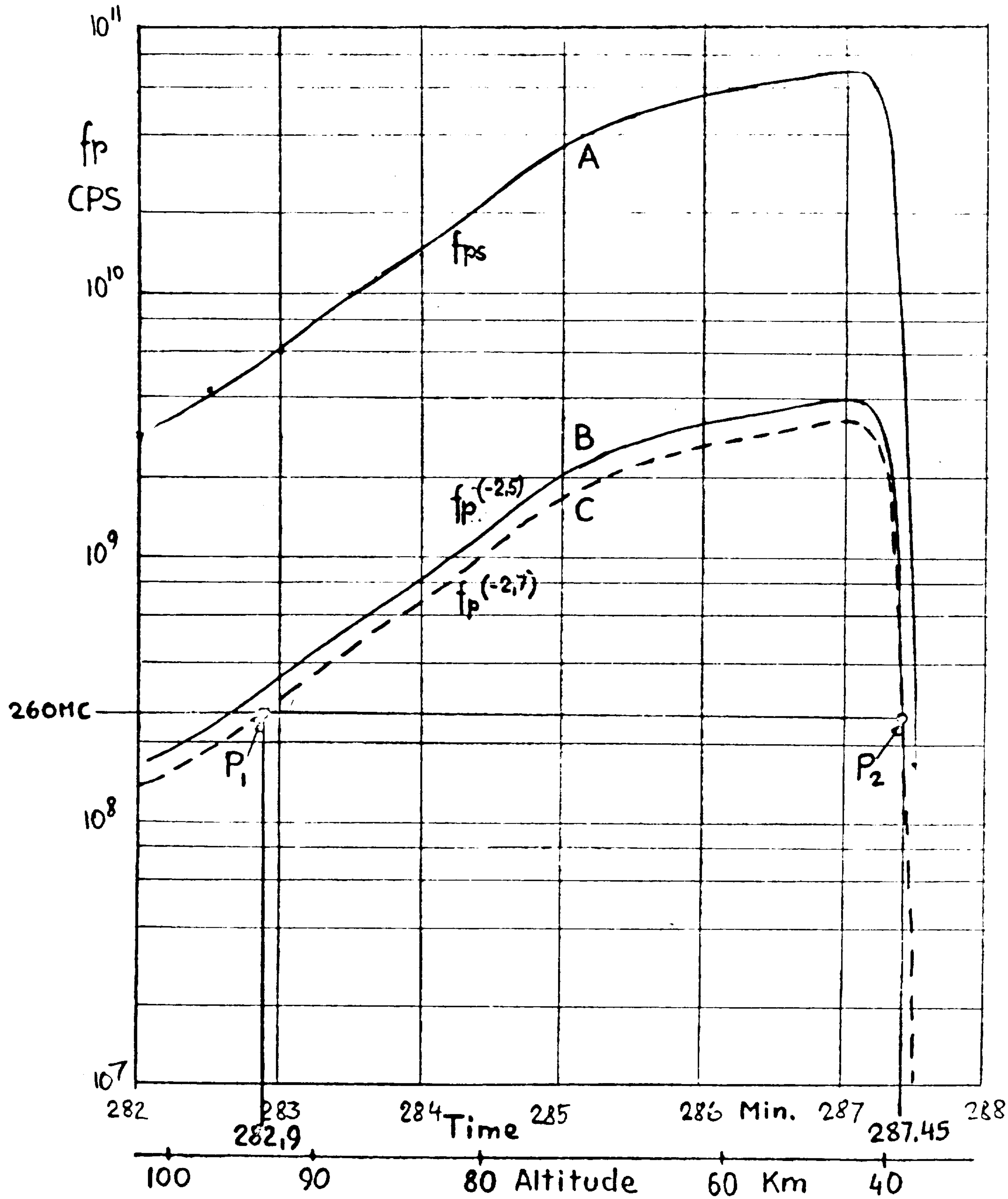

Fig. 3 Maximum Plasma Frequency During Re-entry of the MA-6 Vehicle
A. In Front of the Vehicle
B. C-band Antennas
C. Telemetry Antennas

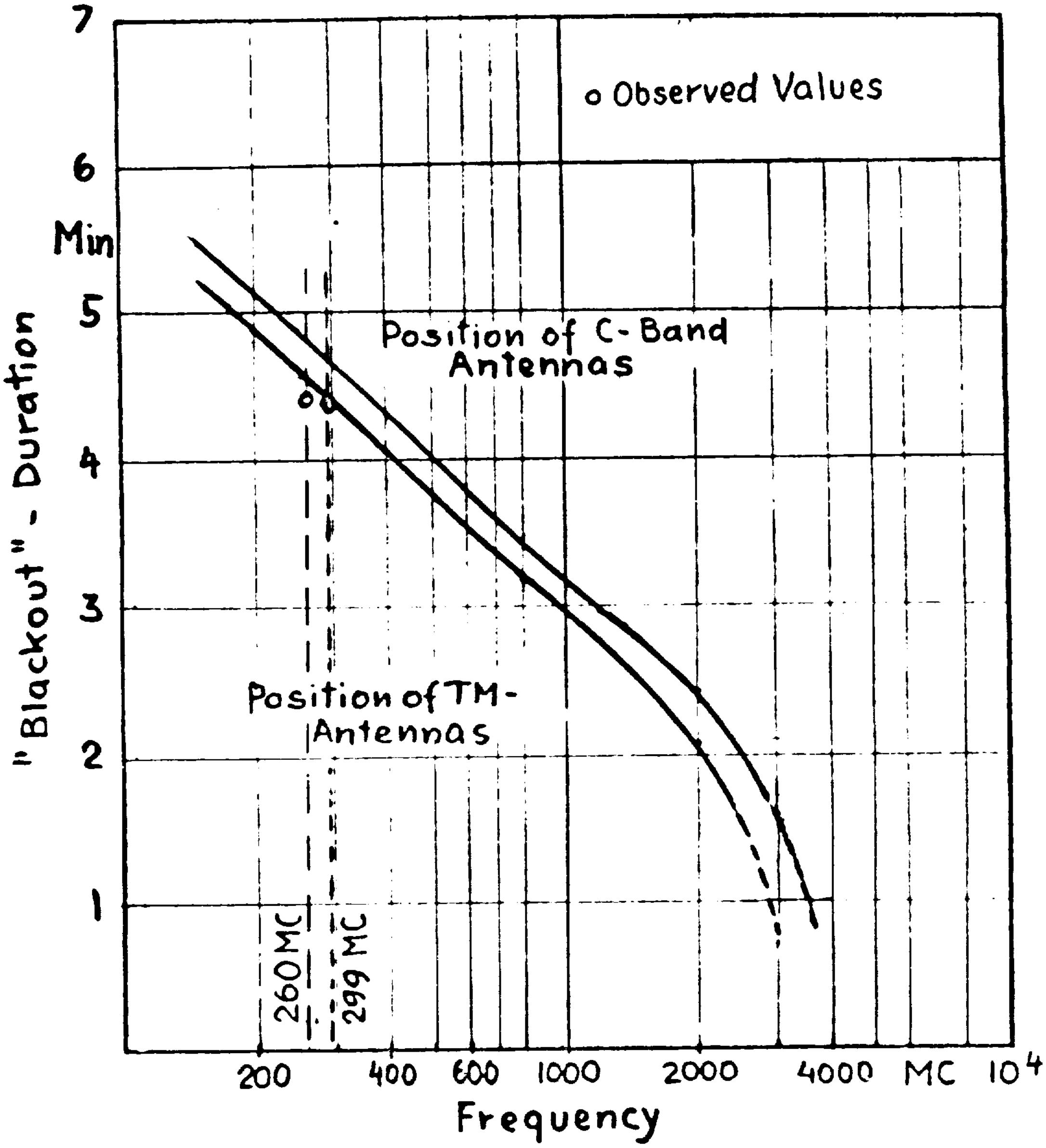

Fig. 4 "Blackout" Duration on MA-6 Mercury Flight